DRILLING AUTOMATION TESTS AT A LUNAR/MARS ANALOG SITE

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Introduction: Space drilling will require intelligent and autonomous systems for robotic exploration and to support future human exploration, as energy, mass and human presence will be scarce. Unlike rover navigation problems, most planetary drilling will be blind – absent any precursor seismic imaging of substrates, which is common on Earth prior to drilling for hydrocarbons. The search for evidence of extant microbial life on Mars drives the need for the eventual acquisition of core samples from subsurface depths estimated at hundreds to thousands of meters where, beneath permafrost, the increasing temperature would be consistent with the presence of interstitial water (as a brine) in its liquid phase. On the Moon, eventual in-situ resource utilization (ISRU) will require deep drilling with probable human-supervised operation [1] of large-bore drills, but initial lunar subsurface exploration and near-term ISRU will be accomplished with lightweight, rover-deployable or standalone drills capable of penetrating a few tens of meters in depth.

The Drilling Automation for Mars Exploration (DAME) project's purpose is to develop and field-test drilling automation and robotics technologies for projected use in missions in the 2011-15 period [2]. Figure 1 shows a lightweight, planetary-prototype drill, in DAME summer Arctic field testing in July 2004 [3]. DAME includes control of the drilling hardware, and state estimation of both the hardware and the lithography being drilled and the state of the hole.

Fig. 1. Honeybee planetary-prototype 10m drill [3], tested with vibration sensors in July 2004 at Haughton Crater on Devon Island, Nunavut, Canada.

Location of Haughton Crater, in Nunavut, Canada [NGS]

Aerial SAR image of the 23km diameter Haughton impact structure.

Approach: Drilling on Earth is hard – an art form more than an engineering discipline. Human operators listen and feel drill string vibrations coming from kilometers underground. A drill system for planetary deployment will differ in many ways from conventional drilling systems where mass, power and volume are not major considerations and where the speed of penetration is essential for economic operation. On the Moon or Mars, working in a very low temperature/pressure desiccated environment without drilling fluids, the basic task of reliably comminuting the rock and moving the cuttings away from the drill bit and up to the surface will itself be a challenge [4]. The environment will be minimally characterized and we can expect to encounter a range of different rock types ranging from regolith to ice to solid basalts, without knowing which rock type we will encounter next. Mass considerations prevent the transport and use of drilling mud.

Lightweight dry drills may break or become stuck quickly in some failure modes, or may degrade progressively in others (such as ice-necking or bit wearout). And the layers being drilled are not known a priori, without prior seismic or other regional surveys… so some apparent wearout or rapid drill faults may actually reflect penetration into subsequent strata (with different mechanical properties). Our approach is to apply three types of automation:

(a) real-time limit-checking and safing, using a rule-based approach to monitor motor torques and temperatures;
(b) near-real-time vibration measurement and fast frequency-domain pattern-matching using a neural net; and
(a) in-line prognosis of degradation and wearout using hybrid model-based reasoning.

Part (a) is being implemented in the drill executive and control software, while (b) and (c) will be separate diagnostic/prognostic software modules.

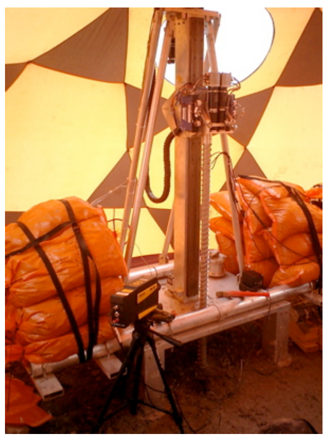
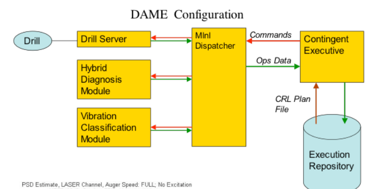
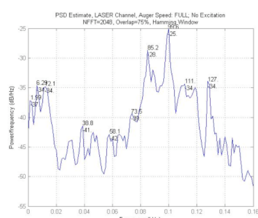
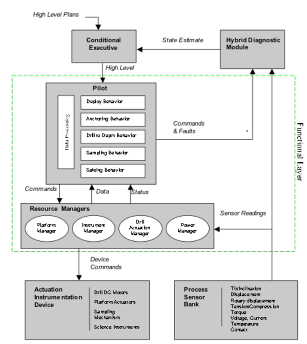


Fig. 2. July 2005 drilling tests at Haughton Crater demonstrated autonomous real-time fault diagnosis while penetrating icy fallback breccia. Laser vibrometer in foreground used speckle interferometry.





Power spectral-density response of the drill (during July 2005 drilling test, laser vibrometer).

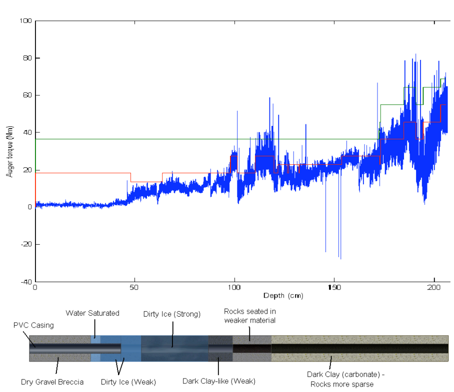


Top-level automation architectureadapted for DAME..

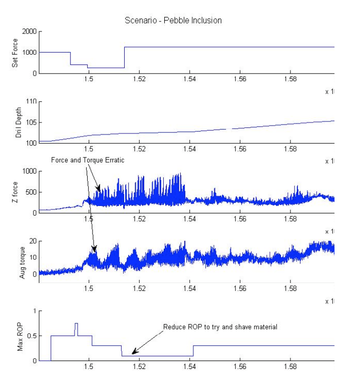
DAME automation architecture: a neural net identifies and classifies vibration patterns, while a hybrid model-based diagnostic module monitors the drilling-performance sensors, both integrated with a drill-system control executive.

Results: The drill was deployed at two sites at Haughton Crater, operating at Mars-relevant power levels (max150-200W). Over eight days, it drilled 2.2m in permafrost and the regolith-like breccia found in the Haughton impact crater. Eight drill faults were demonstrated during testing, as well as nearly 50 hours of nominal operations. Drilling operations were halted periodically in order to capture the vibrational signature of the drill at different depths/lengths.

In the DAME field tests in July 2005 in Haughton Crater in the Canadian Arctic, in addition to testing mechanical drill operations, the DAME team integrated the Honeybee Robotics drill with the NASA-developed automated controls. DAME is intended to develop and test drill fault diagnosis and recovery, so the observe-only diagnostics and monitoring fielded in summer 2005 tests at Haughton will lead to the DAME software in hands-off control of drilling in the summer of 2006. The 2005 DAME tests, shown in Figure 2, used two diagnostic agents – one that used model-based reasoning from sensor values [2], the other a neural network that perceived the vibrational frequency and modal signatures of the drill shaft [5] – which were successfully tested, independently detecting five fault states and reporting their findings to the executive, which itself was developed for the MARTE project [6, 7]. Figure 3 shows the drill response to an ice-embedded pebble beginning at 102 cm depth, and corrective actions taken.



July 2005 Results: Auger torque (N-m) vs. depth (cm) into breccia unit.



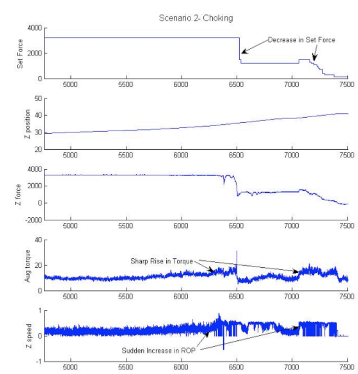


Fig. 3. 2005 field test fault examples – (a) ice-cemented pebble, jamming the auger beginning at 102cm depth, (b) auger choking due to unremoved cuttings

Conclusions: The Drilling Automation for Mars Exploration (DAME) project is developing and testing standalone automation at a lunar/martian impact crater analog site in Arctic Canada. The search for resources and past/present life on other planetary bodies will require subsurface access, which requires exploratory drilling. Drilling has been a hard, human-intensive problem in terrestrial applications, but planetary drills require automation. The DAME project has taken initial steps toward developing hardware and software, two complementary diagnostic approaches, and completing two field tests leading to drilling automation. Full hands-off automation is expected to be tested in the next 2006 Arctic field season.

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References: [1] Glass, B. and G. Briggs (2003) *iSAIRAS 2003*, Nara, Japan. [2] Glass, B. et al. (2005) *iSAIRAS 2005*, Munich, Germany. [3] Paulsen, G.L. et al. (2006) *submitted to 37th LPSC*. [3] Blacic, J. et al. (2000) *AIAA Space 2000*, Long Beach, CA, Paper AIAA-2000-5301. [4] Luo, H, and S. Hanagud (1996) *Technical Report*, Georgia Institute of Technology, School of Aerospace Engineering. [5] Stoker, C. et al. (2004) *35th LPSC*, Abstract 2025. [6] Stoker, C. et al. (2005) *36th LPSC*, Abstract 1537.